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HELMET MOUNTED DISPLAY FORMAT AND SPATIAL AUDIO CUEING FLIGHT TEST

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Historically, the objective of new technology development has been to enhance pilot performance (such as situation awareness) without causing problems such as Spatial Disorientation (SD). However, when improperly designed or poorly integrated, such technologies may actually reduce performance and increase the likelihood of unintended consequences. SD continues to be a serious problem in the military flight domain and it is critical that both the potential to cause problems as well as support effective defensive mitigation strategies be considered early in the development of new technologies. Past research has shown that new technologies can change operator behaviors. For example, the availability of visual information provided via Helmet-Mounted Displays (HMDs) results in pilots looking farther off-axis for longer durations than when the information is not provided. This paper discusses an ongoing flight test that is conducted on an instrumented L-29 fighter jet trainer that is equipped with a Spatial Audio Horizon Cueing (SAHC) system and an HMD with a conformal referenced (CR) symbology and a forward referenced (FR) symbology. The participants are fighter pilots conducting a series of flight maneuvers while tracking targets with an HMD cueing system. We are investigating the effectiveness of SAHC, in dynamic flight, in conjunction with HMD symbologies, as audio cueing has a high probability to transition into the latest generation fighter aircraft, where seamless integration will be critical to ensure reliable information is consistent with, and complementary to, the existing visual symbology.

Introduction

Spatial Disorientation (SD) is a leading cause of aviation mishap fatalities. A recent review of 601 USAF Class A mishaps from 1993 to 2013 found SD to be causal in 72 (12%) of these mishaps, resulting in 101 fatalities (Poisson & Miller, 2014). The same review compared fatality rates of Non-SD and SD-related mishaps and found that 16.1% of Non-SD mishaps involved a fatality while a staggering 61.1% of the SD-related mishaps were fatal. Similarly, the US Navy cites SD as the number one human factors cause of mishaps (Gibb, Musselman, & Farley, 2012). The military aviation operating environment and the unique technologies utilized there represent a particularly high threat of exposure to SD. Helmet-Mounted Display (HMD) technology is heavily relied upon as a primary pilot/vehicle interface within some 5th generation military aircraft, but it is still mostly unknown how different symbology content and formats may affect SD. One of the main affordances of the HMD is information can be displayed anywhere along the pilot's line-of-sight off the aircraft centerline axis. In terms of SD, significant questions arise regarding what information is needed to support basic orientation while off-axis tasks are being performed. We are undertaking a multi-year effort to determine how that information should be portrayed to balance primary and supportive needs while preventing SD. This applied research project uses an operationally representative testbed aircraft, the OPL L-29 fighter jet trainer, equipped with a fielded-system-representative HMD to compare 3 different off-axis symbology formats, each with and without spatial audio horizon-location cueing, to determine the combination which best mitigates SD and improves performance during operationally representative air-to-air scenarios. One major independent variable manipulation is the comparison of forward referenced aircraft attitude information to symbology that is conformal to the natural horizon both on- and off-axis. A second manipulation is the addition of spatialized audio orientation reference to the outside world to assess its ability to enhance the usefulness of the otherwise exclusively visual symbology. At this stage, the spatial audio cueing is still undergoing laboratory testing at NAMRU-D and AFRL to determine the best spatial arrangement of the localized sound source. We are investigating a modality of the spatial audio system that works similar to a sky pointer or a ground pointer in a Head Up Display (HUD).

Test Objectives

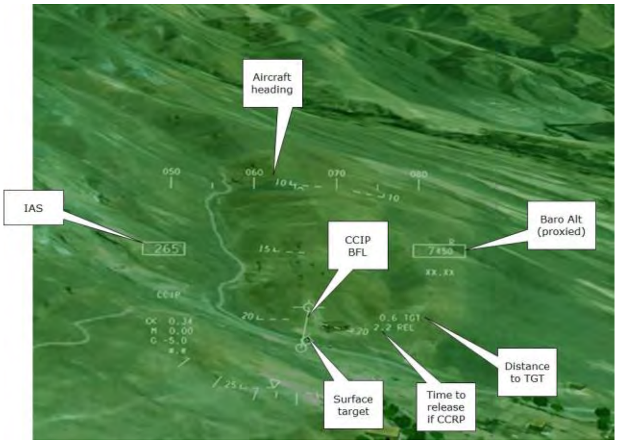
This project will use an operationally representative testbed aircraft, the OPL L-29 fighter jet trainer, equipped with an HMD system to compare 3 different off-axis symbology formats, each with and without spatial audio horizon-location (SAHC) cueing, to determine the combination which best mitigates SD and improves performance during operationally representative air-to-air scenarios. At the time of this writing, we are in the airworthiness approval stages. The specific test objectives are as follows: 1) Compare three different HMD formats, each with and without spatial audio horizon-location cueing, to determine which combination best mitigates SD and improves pilot performance during operationally representative air-to-air scenarios in the actual flight acceleration environment, and 2) Present the same air-to-air scenarios in the DRD and compare the results to actual flight performance for DRD validation purposes.

Experimental Apparatus

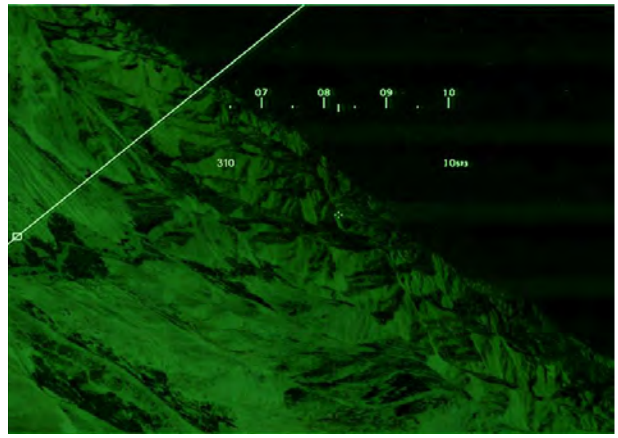
A 5th generation fighter aircraft representative Helmet Mounted Display (HMD) was integrated in the OPL L-29 instrumented flight test aircraft and connected to a head-tracked graphics processor that serves as a simulated Distributed Aperture System (DAS) for use in real flight. With this methodology, the Evaluation Pilots (EPs), who are wearing the HMD, can experience a highly realistic DAS environment while operating the L-29 aircraft from the back seat crew station as if they were in a single seat 5th generation HMD fighter environment.

Experimental Procedures and Symbologies

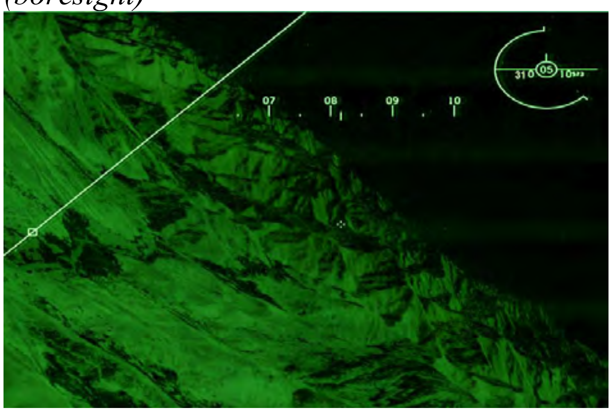
Figure 1 shows the symbologies that will be used in this study. The upper left image is a view of the Virtual Head Up Display (vHUD) symbology that will be seen by the evaluation pilot (EP) in the HMD when he/she is looking forward (bore sight). The test symbologies of interest (Figure 1 upper right, lower left, lower right) will be visible only when viewed off axis or Off Bore-Sight (OBS). Specifically, these symbologies are rendered in the HMD when the pilot’s line-of-sight deviates more than 15 degrees laterally or 25 degrees vertically from the aircraft centerline. The upper right image in Figure 1 shows the first OBS test symbology, the Current Display Format (CDF), which was evaluated in the previous test. This symbology is representative of what is available OBS in the baseline aircraft. The CDF displays head-heading, a line-of-sight + symbol (aiming reticle), airspeed, and altitude. There is, however, no aircraft attitude symbology, necessitating cross-check back to the vHUD for attitude reference.



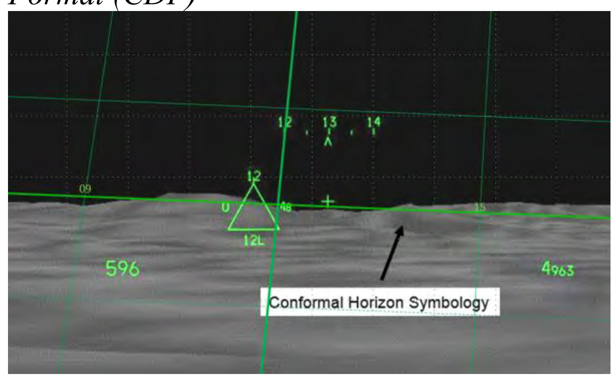
Symbology example of vHUD, looking forward (boresight)



Off-Boresight Symbology #1, Current Display Format (CDF)



Off-Boresight Symbology #2, Forward Referenced (FR) or Non-Distributed Flightpath Reference (NDFR)



Off-Boresight Symbology #3, Conformal Attitude Reference (CR)

Figure 1. HMD Symbologies used in Phase II

The head-heading indicator correlates to aircraft heading, but directly indicates the heading of the pilot's line of sight. The second test symbology is a Forward Referenced (FR) attitude symbology (lower left image in Figure 1). This symbology is the Non-Distributed Flightpath Reference (NDFR), which was also evaluated in the previous flight test. "Forward Referenced" refers to the fact that the attitude symbology is helmet-stabilized and visible in the same position in the pilot's forward line-of-sight OBS. The NDFR provides attitude, airspeed, aircraft heading, and altitude in one combined symbol. The attitude symbol is a modified arc-segmented attitude reference (ASAR), which changes shape and position with climb/dive and bank of the aircraft, surrounding a fixed aircraft symbol. During straight and level flight, the ASAR is a perfect semicircle below the aircraft symbol with the ends touching the wingtips of the aircraft symbol. As flight path angle decreases, the ASAR gets larger (symbolizing "more earth" in view), approaching a full circle at 90 degrees nose low. Conversely, increases in flight path angle decrease its size. With changes in bank, the ASAR moves around the aircraft symbol, such that the aircraft symbol appears "in the turn." In the example shown, the aircraft is in a slight diving, left-banked turn. The digits "05" in the center of the NDFR (in the left image) represent the rounded heading of the aircraft (around 050 degrees). Altitude and airspeed are 10,573 ft MSL and 310 knots respectively. In the current test, this symbology will be displayed in the lower right-hand corner of the pilot's OBS field of view, rather than the upper right, due to the differing nature of the experimental task. Additionally, due to subjective feedback from EPs in the previous test, the numbers will be slightly larger than shown in Figure 2. The third test symbology is the Conformal Attitude Reference (CR) shown in the lower right image of Figure 1. "Conformal" refers to the fact that the attitude symbology, in this case, is world-stabilized rather than helmet-stabilized. In addition to airspeed, altitude, aircraft heading, and head heading, the CR displays a virtual horizon line which overlays the true horizon as long as the pilot is looking in a direction that keeps the true horizon within the HMD field of view. Additional lines will be drawn above and below the horizon line at 10 degree increments from -90 degrees near nadir to the +90 degrees near the zenith. Vertical lines will be drawn at 30 degree increments of heading. If the true horizon line is above or below the HMD field of view, a decluttered version is rendered where the horizon line becomes dashed and is caged at the proper position (parallel to the actual horizon) on the HMD. A potential issue here is that the pilot may know the <u>direction</u> to the horizon, but may not know the <u>distance</u> to it.

As a possible solution to the issue mentioned above, Spatial Audio Cueing (SAHC) will be integrated into the HMD using 2-channel 3D stereo audio. SAHC will use aircraft state and head tracker data to provide an auditory stimulus dependent on aircraft and head position. Two SAHC conditions will be presented: SAHC On and SAHC Off. The SAHC system works similar to a sky pointer or a ground pointer in a Head Up Display (HUD). The idea is that the sound would be localized on the ground directly beneath the aircraft if the spatial audio cue were to work as a ground pointer, or at the zenith above the aircraft, if it were to function like a sky pointer. Pilot testing is currently underway to determine the best mapping (i.e., to nadir or zenith). In either case, the sound would be lateralized according to the roll angle and longitudinalized based on the flight path angle. The sound is a continuously repeating train of three white noise pulses of 100 ms duration with 100 ms pauses followed by a 500 ms pause. The sound attenuates as a function of angle of bank and climb/dive such that it is at its quietest when the aircraft is level, and loudest when it is at an increasingly unusual attitude in terms of bank and/or flight path angle. The sound is localized in an earth referenced fashion (nadir or zenith) so that its location can serve as a bank-away-from or pitch-away-from cue. Display format (CDF, NDFR, CR) and SAHC condition (without/with) will be combined factorially in a 3x2 repeated-measures design. Each of the three display formats (CDF, NDFR, CR) will be tested with and without SAHC for a total of 6 experimental conditions, or scenarios. Each will be tested once in the simulator and once in live-flight for all EPs. Both display format and presence of SAHC will be within-subjects factors. A "rare event", described in the next section, will occur on the last live-flight run for each EP. Presentation order of the display format and SAHC conditions will be counterbalanced across the 12 EPs to control for learning effects. The simulator and flight portions of the experiment will each consist of 6 flights, one per scenario. For each scenario, the EP will fly a figure-eight pattern while executing a visual tracking task (further explained below). Initial (reference) heading for each run will be a cardinal heading such as due north (360). The EP will begin by setting the bank angle to 60 degrees right wing low (RWL) and initiating a descending turn. He/she will continue for 360 degrees (heading) and descend 1000 ft while maintaining aircraft bank at 60 ±15 degrees. Upon completion of the first circle (crossing reference heading), the EP will reverse course and execute a 60 degree left wing low (LWL) banked turn in the opposite direction to complete the figure-eight. During the second circle, the EP will climb 1000 ft to the original starting altitude. The EP will repeat the figure-eight a second time in the scenario (total of two figure-eights or four circles). Each scenario involves a visual tracking task that requires the pilot to put the HMD center reticle onto a displayed target designation (TD) box. At a random time within 30 seconds after initiation of the first turn of each scenario, a distant object will appear in the EP's OBS visual field-of-regard (above horizon and left or right of vHUD). The object will be superimposed with a TD box rendered on the HMD. The EP will be instructed to place the object in the center of the HMD field-of-view (FOV) and track it (aligned as closely as possible with the aiming reticle) for as long as it remains visible. The object will drift up and down in a sinusoidal pattern. During the final live-flight scenario (last (6^{th}) run), once per EP), the object will depart from the sinusoidal drift pattern in a downward motion into the lower portion of the EP's FOV (below the horizon) and continue on this trajectory. This event is intended to produce an unexpected and potentially disorienting stimulus as a rare event to elicit a measurable flight technical deviation. The EPs will be instructed to adhere to the flight technical parameters discussed in the previous section. Deviations (errors) will be scored. We will also assess spatial orientation performance through the number of significant aileron control reversals (ACR) and elevator control reversals (ECR) exceeding +/- 10 degrees of stick input. Head tracking will be used to determine where pilots were looking, and to infer what information they were seeking and how the HMD impacts this behavior. Some inferences about situation awareness may also be possible when analyzed in conjunction with flight technical performance measures. Specific metrics used in the previous test and planned for this test include duration spent OBS (as percentage of total time), rate of OBS looks or crosscheck frequency (looks per minute), and average duration of each OBS look (seconds). Workload and Situation Awareness will also be assessed. Workload refers to the cost an operator incurs in the performance of a task and may be measured subjectively or objectively (Kramer, 1991). Subjective workload will be assessed by the EP after each run using the Bedford Workload Scale (Roscoe & Ellis, 1990). Electrocardiogram (ECG) will be used to objectively assess workload in real-time using the Cognitive Assessment Tool Set (CATS).

Phase I Results

At this time, we have no data for Phase II of this project as the flight test has not yet started. In lieu, we are showing data from the Phase I flight tests as it illustrates the significant benefits that can be derived from enhancements in OBS symbology. Phase I also used three OBS symbologies. They were 1) Current Display Format (CDF), 2) Distributed Flight Path Reference (DFR), and 3) Non-Distributed Flight Path Reference (NDFR). The scenario involved providing nighttime Close-Air-Support (CAS) to a Joint Terminal Attack Controller (JTAC). During the first scenario of each sortie, the EP checked in with the JTAC, as stated by the briefed simulated air tasking order. The JTAC then provided a situation report, issued an altitude clearance limit, and provided a nine-line brief for the first attack. Following issuance of the nine-line, the JTAC provided a visual Talk-On to the intended first target using visual references that were available on the placemat product/map and which the EP had to identify visually using the HMD DAS. Once the target was identified, the JTAC requested immediate time-on-target for either a show-of-force (SOF) or a bomb-on-target delivery. The full report (Schnell T. et al., 2017) details many different measures of effectiveness. Due to page limitations in this paper, we show one example of a tactically important result, the time it takes to complete the Talk-On. The OBS attitude information available in the DFR reduced the EPs' need to sample the HUD, allowing them to maintain eye-contact with the target area more consistently and for longer durations, thus shortening the overall time required to visually acquire the target. Over numerous measures of effectiveness, including the one highlighted in this paper, the DFR provided the overall best performance during OBS tasks while at the same time being a symbology of minimal clutter. With regard to the duration of the Talk-On, the DFR provided a far shorter duration of around 2 minutes when compared to the duration of 4.4 minutes obtained with the CDF. With a Talk-On duration of 2.7 minutes, the NDFR resulted in a respectable reduction as well. From a flight technical standpoint, the DFR provided the most stable aircraft platform. The DFR and NDFR showed a significant improvement over the CDF, requiring fewer check-looks to the vHUD during the OBS task of the Talk-On phase. In this rubric, the NDFR slightly outperformed the DFR and both test symbologies performed better than the CDF on the tactically significant Talk-On time metric.

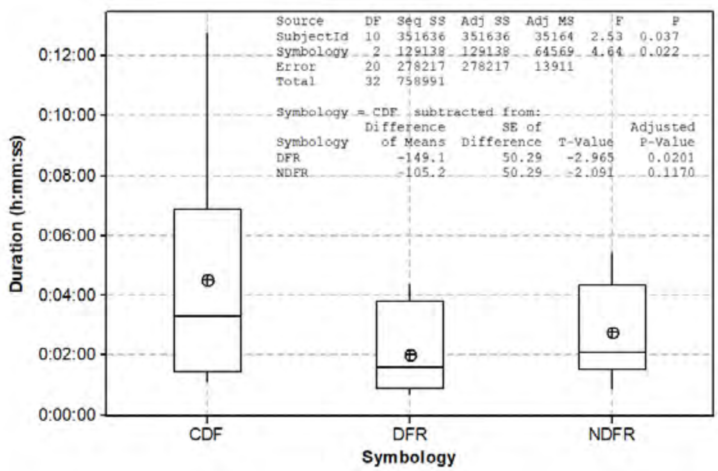


Figure 2. Talk-On Duration by Symbology for N1 Sortie

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